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CONSTRUCTED WETLAND TREATMENT OF SWINE WASTEWATER

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Summary:

Six, 4 X 30-m, constructed wetland cells were planted to rushes, bulrushes, bur-reed, cattails, rice, or soybean. Diluted swine wastewater was added at a N-loading rate of 3 kg ha^{-1} day^{-1}. Saturated culture soybean and rice gave good yields. Nitrogen was lowered from a mean of 12 mg L^{-1} to $<$ 4 mg L^{-1} in all cells during the initial summer operation. Wetlands soils were oxidatively reduced, and nitrogen remained in the ammonia form. An oxidative component appears to be necessary for nitrification/denitrification removal of nitrogen.

Keywords:

Nitrogen, Phosphorus, Redox potential, Rice, Saturated culture soybean

Other Contributors:

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INTRODUCTION

Swine production has become a major enterprise in the Eastern Coastal Plain. In 1990 Sampson Co., NC, and contiguous Duplin Co. were the largest and third largest swine producing counties in the USA, respectively (NC Agric. Stat. Div., 1990). This scale of animal production has large waste generation and disposal considerations. Wastewater disposal must be done in a reliable and sustainable manner to avoid significant environmental damage to shallow ground waters and nutrient-sensitive streams of the coastal environment (Evans et al., 1984; Hubbard and Sheridan, 1989; and Stone, et al. 1989 and 1992).

Swine wastewaters are highly concentrated in nutrients (C, N, and P), and their liquid nature makes the cost of transporting or pumping very expensive. Thus, disposal can be a difficult problem for producers that have limited land near their swine operations. Constructed wetlands have received considerable interest as a method of wastewater treatment that could reduce the land requirments (Hammer, 1989 and Reed, 1993). However, questions exist about the long-term efficiency of constructed wetlands for swine wastewater treatment; specifically, questions exist about loading rates, oxidative/reductive conditions, denitrification potential, phosphorous removal efficiency, and ammonia toxicity to wetland plants.

This study was undertaken to investigate the capacity of constructed wetlands which contained either natural wetland plants or water tolerant agronomic plants to treat swine wastewater.

MATERIALS AND METHODS[1]

Wetland Cell Layout: Six, 4 x 30-m, wetland cells were constructed in Duplin Co., NC, in 1992 for swine wastewater treatment. The six cells are divided into three parallel sets of two end-on-end cells (Fig. 1). The cell bottoms and side walls were lined with clay which was topped with 20 to 30 cm of loamy sand soil.

Monitoring Equipment: Six V-notch weirs and six PDS-350 ultrasonic open-channel flowmeters (Control Electronics, Morgantown, PA) were installed at the inlet and outlet of each set of cells. A CR7X data logger (Campbell Scientific, Logan, UT) with three multiplexers was installed for hourly data acquisition of flow, weather parameters, and soil

[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agr. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

redox potential. Seven ISCO 2700 samplers were installed. One sampler took samples of the wastewater inflow, and the other six sampled the water at the end of each single cell. The water sampler combined hourly samples into daily composites.

Plant Materials: Four cells were planted to natural wetland vegetation in 1992. One set of two cells (two cells end-on-end) contained rush (*Juncus effusus*) and bulrushes (*Scirpus americanus*, *Scirpus cyperinus* and *Scirpus validus)*, and another set of two cells contained bur-reed (*Sparganium americanum*) and cattails *(Typha angustifolia* and *Typha latifolia)*. The third set of two cells contained agronomic crops. One cell contained soybean (*Glycine max*) grown in soil saturated culture on one-meter-wide beds that were flanked by ditches of approximately 10-cm depth (Cooper et al., 1992 and Nathanson et al., 1984). Water level in the ditches was held at about 5 cm below the surface. Group V (cvs. Essex, Holladay, and Hutcheson) and group VI (cvs. Brim, Centennial, and Young) soybean cultivars were planted in 18-cm wide rows. The other agronomic cell contained flooded rice (*Oryza sativa* cv. Maybelle). Both agronomic crops were planted in May 1993, and plant densities were 750,000 plants ha^{-1} in both cases.

Physico-Chemical Analysis: Water samples were analyzed for electrical conductivity (EC) and pH by electrometric methods. Nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), ortho-phosphate (*o*-PO_4), and total phosphorus (TP) analyses were done in accordance with the USEPA recommended methodology by use of a TRAACS 800 Auto-Analyzer (Kopp and McKee, 1983). Soluble organic carbon (SOC) was analyzed with a Dhorman DC-190 carbon (C) analyzer, and chemical oxygen demand was analyzed by use of the Hach method (Gibbs, 1979). Soil redox potential was monitored continuously with a total of ninety Pt electrodes arranged in three clusters of five electrodes per cell with one Ag/AgCl reference electrode per cluster (Faulkner et al., 1989). Redox potential readings were taken every five minutes, averaged every hour and stored in the CR7X datalogger. Redox readings were adjusted to the standard hydrogen electrode (Eh) by adding 200 mV.

Nutrient Loads: We wished to start wastewater application to the cells with light NH_3-N loading rates. Therefore, wastewater (Table 1) was diluted to a 1:15 ratio with fresh water, and applied at a N rate of 3 kg ha^{-1} day^{-1}. This low daily N application rate required a high dilution in order to maintain the hydraulic conditions of a wetland (i.e. wastewater with 25 mg L^{-1} N provides 3 kg ha^{-1} day^{-1} of N with a loading depth of only 12 mm day^{-1}). Since 6-mm hydraulic loading would not meet ET demands during the summer months, the dilution and hydraulic loading were increased as needed to maintain the wetland and the 3 kg ha^{-1} day^{-1} N application rate.

Table 1. Characteristics of non-diluted wastewater from the anaerobic lagoon.

PARAMETERS	UNITS	MEAN	STD. DEV.
pH		7.53	0.14
TS	(g kg^{-1})	1.86	0.47
VS	(g kg^{-1})	0.73	0.32
TOC	(mg L^{-1})	235	124
COD	(mg L^{-1})	737	237
BOD_5	(mg L^{-1})	287	92
TKN	(mg L^{-1})	365	41
NH_3-N	(mg L^{-1})	347	52
NO_3-N	(mg L^{-1})	0.04	0.03
TP	(mg L^{-1})	93	11
o-PO_4	(mg L^{-1})	80	9

RESULTS

All equipment for pumping, diluting, and measuring flow and distribution has worked well and required little maintenance during this start-up period. The continuous flow loading was automated with float control valves in the mixing tank which provided automated loading of the desired proportion of lagoon liquid and dilution water. Outflow from the mixing tank for loading to the wetland cells was controlled by valves which were periodically manually adjusted. Effluent from all three wetland series was pumped back to the lagoon in order to avoid any problems with discharge requirements. The lagoon wastewater was pumped onto crop land as needed for storage space during the summer. Neither odors nor mosquitos were a problem.

During periods of high temperatures and low rainfall, standing water was not maintained throughout cells 2 and 4. Vegetation planted in cells 1 and 2 remain predominant; whereas, intrusion of voluntary species occurred in cells 3 and 4. As temperatures lowered, standing water was maintained in all wetland cells.

A half section of 6-inch PVC pipe was used to distribute flow across the width of the constructed wetland cells. However, streaming occurred near the discharge of the second cell in each series during periods when standing water was not maintained throughout that wetland cell.

The rice yield was 2.8 Mg ha^{-1} which is an acceptable production yield. Groups V and VI soybean yielded, 1.9 and 3.3 kg ha^{-1}, respectively. Soybean yields are not as large as those reported by Cooper (1992), but there were substantial cultivar differences including some high yields. Thus, it appears that there is high yield potential for soybean in saturated culture when swine wastewater is used for irrigation.

The electrical conductivity of the applied wastewater was significantly lowered by flow through the *Juncus* sp. and *Scirpus* sp. wetland cells (Fig. 2). Similar trends were observed in the other four cells (data not shown). This decreased EC indicated that there was a lowering of total electrolytes probably by several mechanisms including precipitation, soil fixation, plant uptake, incorporation into soil organic matter, ammonia volatilization, and denitrification.

Average daily pH values ranged from 7.5 to 8.1 (Table 2). However, higher pH values may have occurred as a result of diurnal algal activity. These higher short-term pH values together with high summer temperatures could have induced NH_3-N volatilization.

Soluble organic C concentrations indicated that energy was available to establish strong anaerobic conditions (Table 3). Wide temporal ranges were observed because the anaerobic lagoon effluent and wetland waters were sometimes significantly diluted by rainfall. Redox potentials indicated strong reducing conditions in all wetland cells (Table 4). These conditions were unfavorable for nitrification. Thus, NH_3-N remained the prevalent nitrogen form. Limited nitrification also prevented significant, subsequent loss of nitrogen by denitrification. The reducing conditions, lack of nitrification/denitrification, and high ammonia-N have been reported to be significant problems for treatment of municipal wastewater in constructed wetlands throughout the USA (Reed, 1993).

Ammonia-N concentrations in the wastewater decreased from 21 mg L^{-1} to < 4 mg L^{-1} after treatment in the rush/bulrushes (cells 1 and 2) and bur-reed/cattails (cells 3 and 4), and it decreased to < 1 mg L^{-1} after treatment in the soybean and rice cells (Table 5). The substantial reduction was probably from plant absorption and NH_3-N volatilization. However, some of the ammonia-N may have been nitrified especially in the soybean and rice cells.

Nitrate-N concentrations were low in the inflow wastewater because of the anaerobic conditions of the lagoon, and very little nitrate-N accumulated in the treated wastewaters (Table 6). These low nitrate-N concentrations along with the low redox conditions and the presence of ammonia-N suggest that very little nitrification/denitrification occurred. However, in wetlands, nitrification/denitrification occurs at the interface of anaerobic and anaerobic zones and more detailed measurements are needed before a firm conclusion can be made about the extent of nitrate-N loss by denitrification.

In the wastewater, phosphorous was present mostly in the form of orthophosphate (Table 7). We believe that its effective removal was predominately by plant uptake, precipitation, and sorption to the soil substrate.

Table 2. Mean and standard deviation for pH of daily composite wastewater samples (June - September 1993).

PLANTS	SAMPLER	MEAN	STD. DEV.
	INFLOW	7.9	0.3
J/S†	CELL 1	7.7	0.3
	CELL 2	7.5	0.3
S/T‡	CELL 3	7.8	0.3
	CELL 4	7.6	0.4
SOYBEAN	CELL 5	8.1	0.2
RICE	CELL 6	7.5	0.3

† J/S = *Juncus* sp. and *Scirpus* sp.
‡ S/T = *Sparganium* sp. and *Typha* sp.

Table 3. Mean, standard deviation and range for soluble organic carbon of daily composite wastewater samples (June - September 1993).

PLANTS	SAMPLER	MEAN (mg L^{-1})	STD. DEV. (mg L^{-1})	RANGE (mg L^{-1})
	INFLOW	12	15	3 - 89
J/S†	CELL 1	17	19	5 - 79
	CELL 2	13	4	6 - 20
S/T‡	CELL 3	13	9	4 - 44
	CELL 4	18	13	6 - 68
SOYBEAN	CELL 5	7	3	5 - 13
RICE	CELL 6	15	4	7 - 20

† J/S = *Juncus* sp. and *Scirpus* sp.
‡ S/T = *Sparganium* sp. and *Typha* sp.

Table 4. Soil redox potential (Eh) ranges for every wetland cell (June - September 1993).

CELL	Eh RANGE (mV)*
1	150 to -240
2	240 to -240
3	100 to -240
4	280 to -220
5	400 to -250
6	165 to -235
* Nitrate is normally absent when soil Eh is below 300 mV.	

Table 5. Mean, standard deviation and range for NH_3-N of daily composite wastewater samples (June - September 1993).

PLANTS	SAMPLER	MEAN (mg L^{-1})	STD. DEV. (mg L^{-1})	RANGE (mg L^{-1})
	INFLOW	21	6	6.0 - 31
J/S†	CELL 1	4	4	0.3 - 13
	CELL 2	2	4	0.3 - 11
S/T‡	CELL 3	3	3	0.1 - 10
	CELL 4	2	2	0.1 - 4
SOYBEAN	CELL 5	8	6	1.0 - 14
RICE	CELL 6	0.2	0.1	0.1 - 0.3

† J/S = *Juncus* sp. and *Scirpus* sp.
‡ S/T = *Sparganium* sp. and *Typha* sp.

Table 6. Mean, standard deviation and range for NO_3-N of daily composite wastewater samples (June - September 1993).

PLANTS	SAMPLER	MEAN (mg L^{-1})	STD. DEV. (mg L^{-1})	RANGE (mg L^{-1})
	INFLOW	1.0	0.3	1.0 - 2.0
J/S†	CELL 1	0.1	0.1	0.01 - 0.2
	CELL 2	0.1	0.1	0.1 - 0.2
S/T‡	CELL 3	0.2	0.2	0.1 - 0.4
	CELL 4	0.1	0.1	0.1 - 0.2
SOYBEAN	CELL 5	0.8	0.2	0.6 - 1.0
RICE	CELL 6	0.1	0.1	0.01 - 0.2

† J/S = *Juncus* sp. and *Scirpus* sp.
‡ S/T = *Sparganium* sp. and *Typha* sp.

Table 7. Mean, standard deviation and range for *o*-PO_4 of daily composite wastewater samples (June - September 1993).

PLANTS	SAMPLER	MEAN (mg L^{-1})	STD. DEV. (mg L^{-1})	RANGE (mg L^{-1})
	INFLOW	4.0	0.8	3.0 - 5.0
J/S†	CELL 1	1.0	0.6	0.2 - 2.0
	CELL 2	0.2	0.1	0.1 - 0.2
S/T‡	CELL 3	0.7	0.6	0.2 - 2.0
	CELL 4	0.1	0.1	0.1 - 0.2
SOYBEAN	CELL 5	2.0	0.4	2.0 - 3.0
RICE	CELL 6	0.3	0.2	0.2 - 0.5

† J/S = *Juncus* sp. and *Scirpus* sp.
‡ S/T = *Sparganium* sp. and *Typha* sp.

Summary

Growth of the rushes, bulrushes, bur-reed, and cattails was very good. Rice yield was 2.8 Mg ha^{-1}, and groups V and VI soybean yielded, 1.9 and 3.3 Mg ha^{-1}, respectively.

The low N loading rate of 3 kg ha^{-1} day^{-1} was chosen because it is a currently recommended level and wetlands with higher loading rates have not been producing an effluent that could be stream discharged. The preliminary results presented are for this loading rate during a four-month period with excellent plant growth. The treated effluent concentrations of nitrogen and phosphorus were low and could have met discharge requirements in some areas; however, longer term research including dormant plant periods is still needed. Phosphorus is of concern on a long-term basis since the highly reducing conditions may lower the removal efficiency.

The redox conditions of wetland soil during this start-up period were highly reduced. The presence of ammonia-N in the discharge effluent and the very low concentrations of nitrate-N throughout the wetlands suggest that the cell did not support nitrification which must occur before removal of nitrogen by denitrification. However, nitrification/denitrification in wetlands occurs at the interface of anaerobic and anaerobic zones and more detailed measurements will have to be made before a firm conclusion can be made about the extent of nitrate-N loss by denitrification.

In any case, an oxidative component and a reductive component in sequence will be necessary for nitrogen removal. If it does not occur in the natural wastewater-plant-soil interface of the wetland cell, it could be produced by construction of an oxidative component and recycling of the effluent. Long-term data over annual cycles for varying crop and hydraulic conditions will be necessary to determine if constructed wetlands can produce a dischargeable or significantly weakened swine wastewater effluent so that less land will be required for wastewater management.

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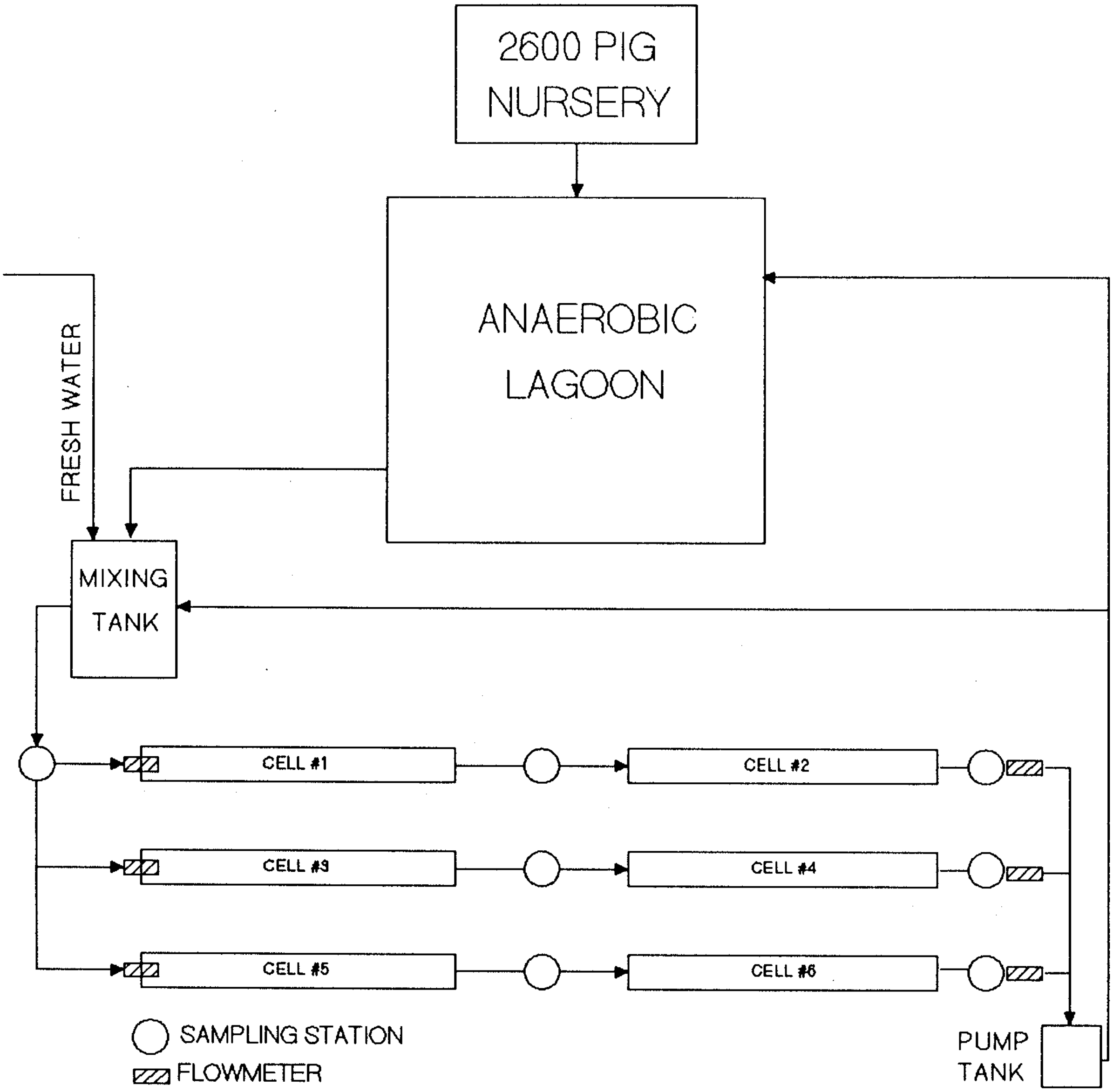

Fig. 1. A schematic of the pig nursery, lagoon and constructed wetlands.

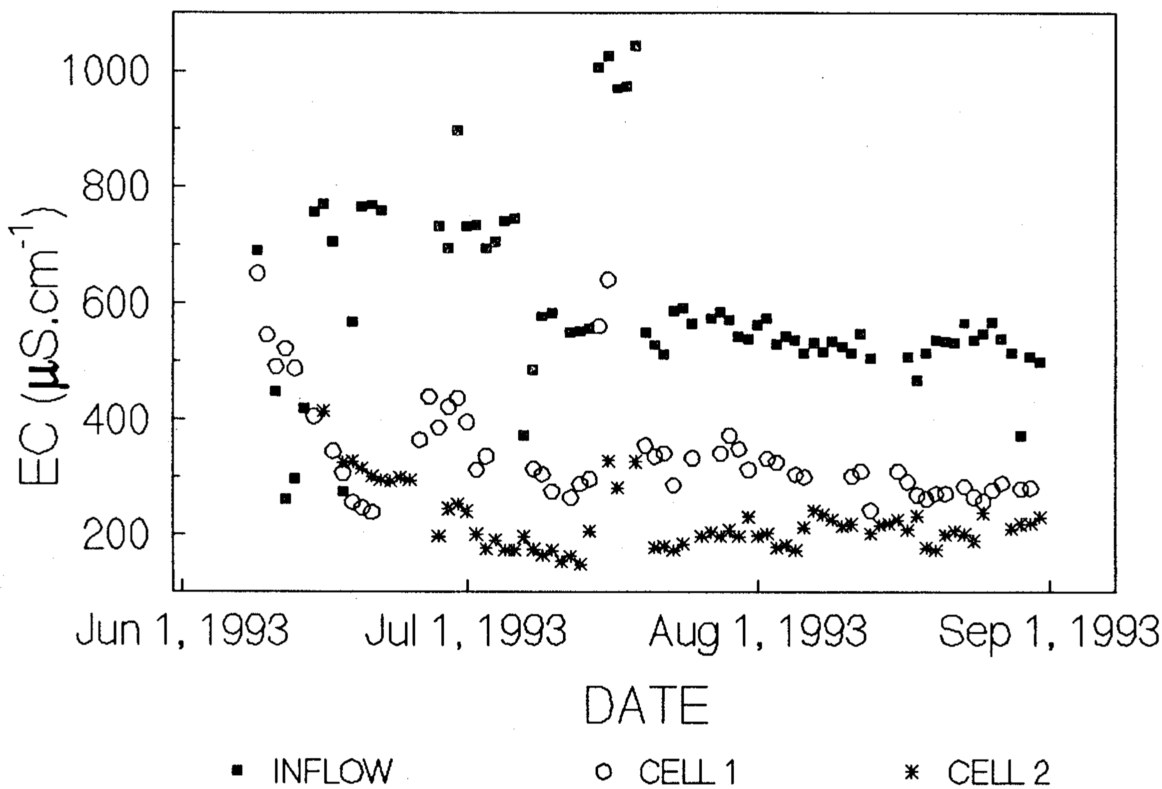

Fig. 2. Daily electrical conductivity of wastewater inflow and treated effluent from cells 1 and 2 (June - September 1993).